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In re Application of:
Hillis, et al.

Serial No.: 10/618,419

Filed: July 11, 2003

Confirmation No.: Unknown

For: Improving Collapse Resistance of Tubing

§ Group Art Unit: 0

§ Examiner: Unknown

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Date

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Dear Sir:

CLAIM TO PRIORITY

Applicant(s) reaffirm the claim for the benefit of filing date of the following foreign patent application referred to in Applicant's Declaration:

Great Britain Application Serial Number 0216074.5 filed July 11, 2002.

A copy of the application certified by the Great Britain Patent Office is enclosed.

Respectfully submitted,

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Dated 11 July 2003

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1.	Your reference	AS\AM\P12164GB
2.	Patent application number *(The Patent Office will fill in this part)*	11 JUL 2002 0216074.5
3.	Full name, address and postcode of the or of each applicant *(underline all surnames)*	WEATHERFORD/LAMB, INC. 515 POST OAK BOULEVARD SUITE 600 HOUSTON TX 77027 UNITED STATES OF AMERICA
	07905987001 Patents ADP number *(if you know it)*	
	If the applicant is a corporate body, give the country/state of its incorporation	DELAWARE CORPORATION
4.	Title of the invention	IMPROVING COLLAPSE RESISTANCE OF TUBING
5.	Name of your agent *(if you have one)* "Address for service" in the United Kingdom to which all correspondence should be sent *(including the postcode)*	CRUIKSHANK & FAIRWEATHER 19 ROYAL EXCHANGE SQUARE GLASGOW G1 3AE SCOTLAND UNITED KINGDOM
	Patents ADP number *(if you know it)*	547002 ✓
6.	If you are declaring priority from one or more earlier patent applications, give the country and the date of filing of the or of each of these earlier applications and *(if you know it)* the or each application number	Country / Priority application number *(if you know it)* / Date of filing *(day / month / year)*
7.	If this application is divided or otherwise derived from an earlier UK application, give the number and the filing date of the earlier application	Number of earlier application / Date of filing *(day / month / year)*
8.	Is a statement of inventorship and of right to grant of a patent required in support of this request? *(Answer 'Yes' if: a) any applicant named in part 3 is not an inventor, or b) there is an inventor who is not named as an applicant, or c) any named applicant is a corporate body. See note (d))*	YES

9. Enter the number of sheets for any of the following items you are filing with this form. Do not count copies of the same document

Continuation sheets of this form	
Description	14
Claim*(s)*	7
Abstract	
Drawing*(s)*	1

10. If you are also filing any of the following, state how many against each item.

Priority documents	
Translations of priority documents	
Statement of inventorship and right to grant of a patent *(Patents Form 7/77)*	
Request for preliminary examination and search *(Patents Form 9/77)*	1
Request for substantive examination *(Patents Form 10/77)*	
Any other documents *(please specify)*	

11. I/We request the grant of a patent on the basis of this application.

Signature CRUIKSHANK & FAIRWEATHER   Date 10 JULY 2002

12. Name and daytime telephone number of person to contact in the United Kingdom

ANDREW SHANKS
0141 221 5767

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Notes

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DUPLICATE

IMPROVING COLLAPSE RESISTANCE OF TUBING

FIELD OF THE INVENTION

This invention relates to improving the collapse resistance of tubing, particularly tubing to be utilised in downhole applications.

BACKGROUND OF THE INVENTION

Bores drilled to access subsurface hydrocarbon reservoirs are lined with metal tubing to *inter alia* prevent collapse of the bore walls and to provide pressure integrity. The characteristics of the bore-lining tubing utilised to line a bore will be based on a number of factors, one being the collapse or crush-resistance of the tubing. This is the ability of the tubing to withstand external radial forces, as may result from fluid pressure or from mechanical forces applied by a surrounding rock formation. The collapse resistance of a section of tubing may be estimated by means of calculations, typically following an American Petroleum Institute (API) standard formulation (API Bulletin 5C3). Alternatively, a section of tubing with its ends blanked off may be immersed in hydraulic fluid which is then pressurised until the tubing collapses.

SUMMARY OF THE INVENTION

It has been found that the collapse resistance of metallic tubing may be enhanced, in a preferred embodiment, by applying radial forces to discrete areas or zones of the tubing, most conveniently by passing a rotating tool through the tubing, which tool includes at least one bearing member for applying a radially directed force to the tubing wall.

In other embodiments of the invention, other means of increasing the strength or hardness of the tubing are utilised, as will be described.

Preferably, at least an inner portion of the tubular wall is subject to compressive yield or other cold working, which effect may also be achieved through other means, for example by hydraulically expanding the tubular within a higher yield strength outer tubular, or within a bore in a substantially unexpandable body of material.

Conveniently, the tool may be a rotary expansion tool, examples of which are described, for example, in applicant's International Patent Application Publication No. WO00\37766, and in the SPE Paper 74548 entitled "The Application of Rotary Expansion to Solid Expandable Tubulars", by Harrall et al. As described in the SPE paper, when such a tool is utilised to expand tubing, the tubular material is subjected to strain hardening

processes, whereby the yield and tensile strength increase as a function of expansion ratio and the expandable material characteristics. However, the collapse resistance of the expanded tubular is of course less than the original unexpanded tubing, due to the decrease in tubular wall thickness and the increase in diameter.

Surprisingly, it has been found that by passing such an energised rotary expansion tool through a tubular and subjecting the tubular to minimal deformation, which may be apparent as an increase in the length of the tubular, a slight increase in external diameter, or creation of undulations or a wave form on the tubular inner surface, the collapse resistance of the tubing may be increased. The procedure may be carried out on surface, before a tubular is run into a bore, or may be carried out downhole, in existing casing or liner. Of course the radial forces utilised to increase the collapse resistance of the tubing may be achieved using other tool forms and configurations.

It is believed that the invention will have particular utility in increasing the collapse resistance of tubulars which have previously been subjected to swage-expansion. As identified in the above-noted SPE paper, one of the primary concerns with swage-expanded tubulars is the detrimental effect of expansion on

collapse performance. It has been suggested that the radial orientation of strain hardening in cone-expanded tubulars, and a subsequent reduction in yield on reversed, collapse loading (Bauschinger effect), is the most likely explanation. Indeed, testing of swage-expanded tubulars indicates that the collapse resistance of such tubulars may be significantly lower than the API 5C3 predictions for given D/t ratios. Thus the invention may be utilised immediately following the swage-expansion of a tubular, or may be carried out as a remedial operation, for example where an operator is concerned that the integrity of a well may be compromised by the presence of swage-expanded tubulars which may provide poorer collapse performance than was originally predicted. Similarly, the present invention may be utilised in instances in which well conditions have or are expected to change to an extent that the collapse resistance of existing casing or liner is deemed inadequate: by means of the relatively simple method of the present invention, the collapse resistance of the tubing may be increased in situ.

Even in applications in which an existing tubular has been cemented in a bore the invention may be utilised to increase the collapse resistance of the tubular.

Although not wishing to be bound by theory, it is believed that the collapse resistance of a tubular can be

enhanced by increasing one or both of the strength and hardness of the inner fibre, that is the inside diameter (ID) or inner portion of the bore wall. Whilst this has been demonstrated by increasing the ID surface strength by strain hardening or cold work, the invention encompasses other means of localised surface hardening using metallurgical transformation or diffusion of elements which promote increased hardness by solid solution, precipitation or transformation strengthening mechanisms. Examples of methods within the scope of the invention include, but are not limited to, cold work by peening or rolling, induction hardening, nitriding and carburising.

The invention also relates to tubulars which have been subject to the method of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

These and other aspects of the present invention will now be described, by way of example, with reference to the accompanying drawing, which is a schematic illustration of a tubular having its collapse resistance increased, in accordance with an embodiment of an aspect of the present invention.

DETAILED DESCRIPTION OF THE DRAWING

The drawing shows a metallic tubular 10, such as utilised in conventional downhole applications. Located within the tubular is a tool 12 similar to the rotary expansion tools as described in WO00\37766. The tool 12 features a hollow body 14 in which are mounted three equi-spaced pistons 16, each piston carrying a roller 18 which is rotatable about an axis substantially parallel to the body main longitudinal axis 20.

The tool 12 is mounted on a pipe string through which pressurised hydraulic fluid is supplied to the tool body 14. This urges the piston-mounted rollers 18 radially outwardly into contact with the inner wall of the tubular 10. The tool 12 is rotated about its axis 20 and advanced axially through the tubular 10.

The rollers 18 impart a radial force upon discrete zones of the tubular's circumference, cold working the zones, and the rotation of the tools 12 about its longitudinal axis 20 applying this radial force with the resulting cold working to the entire inner circumference of the tubular 10, or at least to a helical path or paths which encompass a substantial proportion of the tubular wall.

The degree of force imparted by the rollers 18 may be controlled by applying a selected fluid pressure, and may be selected to provide a small degree of diametric

expansion to the tubular 10. Alternatively, there may be no appreciable diametric expansion experienced by the tubular 10, the deformation of at least the inner surface of the tubular being accommodated by creation of undulations in the inner wall surface or by an increase in the length of the tubular. Indeed, in many downhole applications there will be no opportunity for diametric expansion, for example if the tubular has been cemented in the bore.

EXAMPLE

In order to demonstrate the benefit in collapse resistance obtained using the rotary expansion method as described above, collapse tests on the same material expanded to the same ratio by cone swage-expansion and rotary expansion were conducted.

MATERIAL

The expanded material was a proprietary cold-finished & normalised aluminium-killed steel designated VM42. The dimensions were 5 1/2" 17# OCTG, i.e. 139.7mm OD x 7.72mm WT. The rotary expanded material was identified as "heat 345640". In the absence of identifiable heat numbers on the cone-expanded specimen, chemical analysis, metallographic examination and mechanical testing were performed to demonstrate that

equivalent materials were tested. In addition to this, a low yield-strength quenched & tempered (Q&T) material of the same dimensions was expanded and collapse tested.

	C	Si	Mn	S	P	Ni	Cr	Mo	Nb	Cu	Al	Ti
Nominal VM42	0.15	0.21	0.94	-	-	0.04	0.10	0.01	-	0.07	-	-
Cone Expanded VM42	0.15	0.20	0.93	0.004	0.014	0.03	0.11	-	-	0.02	0.034	-
Rotary Expanded VM42	0.14	0.24	0.98	0.002	0.013	-	-	-	-	-	0.029	-
Rotary Expanded Q&T	0.11	0.36	1.27	0.002	0.017	0.36	0.11	0.01	0.022	0.23	0.049	0.02

Analysis by Optical Emission Spectrometry.

The pre-expansion longitudinal and transverse tensile properties are shown below. Longitudinal testing was conducted in accordance with BS EN 10002 Pt 1: 2001.

		VM42	Q&T Material
Ultimate Tensile Stress	**MPa** **Ksi**	469 – 481 68.0 – 69.8	538 78.0
0.2% Offset Proof Stress	**MPa** **Ksi**	344 – 357 49.9 – 51.8	442 64.1
Elongation	**%**	37 – 41	29
Cross Sectional Area	**mm^2**	-	94.07
Gauge Length	**mm**	50.8	50

Metallographic specimens were prepared from the expanded cone and rotary expanded VM42 material and also the Q&T steel. The VM42 material possessed a banded ferrite-pearlite microstructure consistent with a

normalised low carbon steel. The Q&T material exhibited a microstructure comprising fine, tempered martensite.

EXPANSION TEST

Data on the cone-expansion was not available, however the dimensions were consistent with an approximate 139mm diameter cone. The OD was 154mm with an average wall thickness of 7.29mm, giving an OD expansion ratio of 10.2%.

The rotary expansion was conducted using 4.75" compliant tool with a single plane of 20° rollers. The expansion was conducted at 4'/min and 50rpm in order to maintain wall thickness by restricting elongation to approximately 2%. The expanded OD was, again, 154mm with the average wall thickness measured at 6.71mm. The Q&T material was expanded in the same way and produced an average wall thickness of 6.79mm.

For the rotary-expanded VM42, the expansion demands comprised an axial force of approximately 20000lbf, generating a torque of 2750ftlbs at a tool pressure of around 1400psi.

POST-EXPANSION TENSILE PROPERTIES

The post-expansion longitudinal tensile properties were evaluated on all three specimens in accordance with BS EN 10002 Pt 1: 2001. The results are listed below.

	Cone Expanded VM42	Rotary Expanded VM42	Rotary Expanded Q&T
Ultimate Tensile Stress	505 73.2	565 82.0	621 90.1
0.2% Offset Proof Stress	485 70.3	521 75.6	570 82.7
Elongation	22.7	18.3	14.8
Cross Sectional Area	90.16	81.31	85.57
Gauge Length mm	50	50	50

COLLAPSE TESTING

The collapse samples were 1430mm, or greater, in length, giving a sample length in excess of 9.2 times the OD. The collapse test was conducted in a sealed vessel at a ramp rate of between 6 and 9psi/second, with the pressure continually recorded during the test. The collapse pressure was determined by the sudden pressure drop, resulting from the instantaneous sample volume change on collapse.

The collapse pressures are tabulated below.

	Cone Expanded VM42	Rotary Expanded VM42	Cone Expanded VM42[1]	Rotary Expanded Q&T
Length	9.29OD	~10OD	>8OD	9.29OD
D/t	21.12	22.93	21.4	22.78
API 5C3 Collapse Pressure Estimate, psi	4119	3405	4012	3663
Actual Collapse Pressure, psi	3232	3830	3147	4127
Difference from Estimate	-21.5%	+12.5%	-21.6%	+12.7%

DISCUSSION

The tests demonstrate that the collapse resistance of compliant rotary expanded tubulars is superior to equivalent tubulars expanded using a cone-swaging method. The collapse pressure obtained for the cone-expanded sample used in these tests was consistent with published results (P. Sutter et al, "Developments of Grades for Seamless Expandable Tubes", Corrosion 2001, Paper no. 021, Houston TX, NACE International, 2001.). Furthermore, whilst the cone-expanded sample exhibited a collapse pressure over twenty percent lower than the API prediction, the two different rotary expanded materials exceeded the API estimate by 12.5%.

The applicant, although not wishing to be bound by theory, attributes the difference in collapse performance between rotary and cone-expanded tubulars to the

orientation of dislocation arrays produced by the differing cold working process, that is the strain path is helical in the rotary process as opposed to radial in the cone method. This means that on loading in a collapse mode, the dislocation substructure for helically-expanded material is not aligned in a way to suffer from the Bauschinger effect, which relies on total or partial reversed loading. An alternative/contributory factor in rotary-expanded collapse performance is the localised concentration of compressive cold work in the bore of the tubular.

Additionally, for casing-compliant expansions, the collapse resistance in annular and full-system collapse tests have developed resistance far greater than would be anticipated from consideration of the individual tubular capabilities. It is believed this is due to the casing resisting the geometry changes necessary for collapse of the internal tubular.

Published data on cone-expanded tubulars demonstrates that a strain-ageing process can recover collapse resistance, presumably by restricting the mobility of dislocations generated by cold work rather than from the increase in the yield strength of the material. However, strain-ageing is a diffusion-related process and, as such, is dependent on exposure of the material to an elevated temperature for a period of time.

As the necessary duration is kinetically related to the exposure temperature, this process is dependent on well-temperature.

An ageing treatment of 5hrs at 175°C is quoted (R.Mack & A Filippov, "The Effects of Cold Work and Strain Aging on the Hardness of Selected Grades of OCTG and on the SSC Resistance Of API P-110 - Results of Laboratory Experiments", Corrosion 2002, Paper no. 066, Denver CO, NACE International, 2002) as a realistic simulation for expanded P-110 material based on a kinetics study. The suppliers have suggested 30mins at 250°C for VM42 material. It is assumed that this study consisted of a series of heat treatments of varying time and temperature to derive activation energies and rate constants as per standard Arrhenius relationships, i.e. by plotting ln(k) vs 1/T to find the gradient and intercept for $k=k_o\exp(-E_A/RT)$. The "reaction" in this case is the strain-ageing treatment to produce peak hardness or "full-pinning".

The cone-expanded VM42 material was tested after more than eight months exposure to ambient temperatures and did not show even a partial recovery of collapse strength when compared to published data (P. Sutter et al).

Finally, following strain-ageing, a rotary-expanded carbon or low alloy steel tubular could be expected to

increase in collapse strength, from its existing high level, by a small extent due to an increase in yield strength.

It will be apparent to those of skill in the art that the above-described embodiment is merely exemplary of the present invention and that various modifications and improvements may be made thereto, without departing from the present invention. For example, in other embodiments of the invention, the radial forces imparted by the rollers 18 as described above may be achieved by other means, for example by use of a tool which is advanced axially without rotation, and which features a plurality of rollers which are rotatable about an axis perpendicular to the tool longitudinal axis, such as the ACE (Trade Mark) tool supplied by the applicant.

In other embodiments, bearing members other than rollers, such as balls or indeed non-rotating members may be utilised to provide the required axial force, although use of non-rotating members would increase the tool-to-tubular friction and increase the forces necessary to move the tool through the tubular.

CLAIMS

1. A method of increasing the collapse resistance of a tubular, the method comprising:

(a) locating a tool having at least one bearing within a tubular;

(b) placing the bearing member in engagement with a wall of the tubular to apply a radial force to a discrete zone of the wall; and

(c) applying said radial force to further discrete zones of the wall,

whereby the level of radial force is selected such that the collapse resistance of the tubular increases.

2. The method of claim 1, wherein said radial force is selected to induce compressive yield of at least an inner portion of the wall.

3. The method of claim 1 or 2, wherein said radial force is selected to induce plastic deformation of at least an inner portion of the wall.

4. The method of claim 1, 2 or 3, wherein the bearing member is a rolling element and the tool is moved relative to the tubular to provide a rolling contact between the rolling element and the tubular wall.

5. The method of claim 1, 2 or 3, further comprising moving the tool relative to the tubular to provide a sliding contact between the bearing member and the tubular wall.

6. The method of any of the preceding claims, wherein the tool is advanced axially relative to the tubular.

7. The method of any of the preceding claims, wherein the tool is rotated relative to the tubular about a longitudinal axis of the tubular.

8. The method of any of the preceding claims, wherein the tool is located within the tubular.

9. The method of any of the preceding claims, wherein the tubular is subject to a degree of diametric expansion.

10. The method of claim 9, wherein the tubing is subject to permanent diametric expansion.

11. The method of any of claims 1 to 8, wherein the tubular experiences little or no diametric expansion.

12. The method of any of the preceding claims, wherein the tool is moved relative to the tubular such that the bearing member describes a helical path along the tubular wall.

13. The method of any of the preceding claims, wherein the tool has a plurality of bearing members, and each bearing member is urged into engagement with the wall of the tubular to impart a radial force to a respective discrete zone of the tubular wall.

14. The method of claim 13, wherein the respective discrete zones are circumferentially spaced.

15. The method of claim 13 or 14, wherein the respective discrete zones are axially spaced.

16. The method of any of the preceding claims, wherein the bearing member applies the radial force to the tubular wall as a point load.

17. The method of any of the preceding claims, wherein the bearing member applies the radial force to the tubular wall as a line load.

18. The method of any of the preceding claims, wherein the bearing member is fluid pressure actuated.

19. The method of any of the preceding claims, wherein the tool comprises a plurality of bearing members and at least one of the bearing members is independently radially movable.

20. The method of any of the preceding claims, wherein the tool comprises a ball-peening tool and is impacted against the inner surface of the wall.

21. The method of any of the preceding claims, wherein the tubular has been previously swage-expanded.

22. The method of any of claims 1 to 20, further comprising swage-expanding the tubular prior to steps (b) and (c).

23. The method of any of the preceding claims, when executed on surface.

24. The method of any of the preceding claims, when executed downhole.

25. The method of any of the preceding claims, wherein the tubular is located within a larger diameter tubular.

26. The method of claim 25, wherein the larger diameter tubular is substantially unexpandable.

27. A method of increasing the collapse resistance of a tubular, the method comprising diametrically expanding the tubular within a larger diameter tubular.

28. A method of increasing the collapse resistance of a tubular, the method comprising applying radial forces to discrete areas of a tubular wall.

29. The method of any of the preceding claims, wherein the tool creates a strain path in the wall of the tubular having a circumferential element.

30. The method of claim 29, wherein the tool creates a circumferential strain path.

31. The method of claim 29, wherein the tool creates a helical strain path.

32. A tubular as treated by the method of any of the preceding claims.

33. A method of increasing the collapse resistance of a tubular, the method comprising increasing at least one of the strength and hardness of at least the inner bore wall.

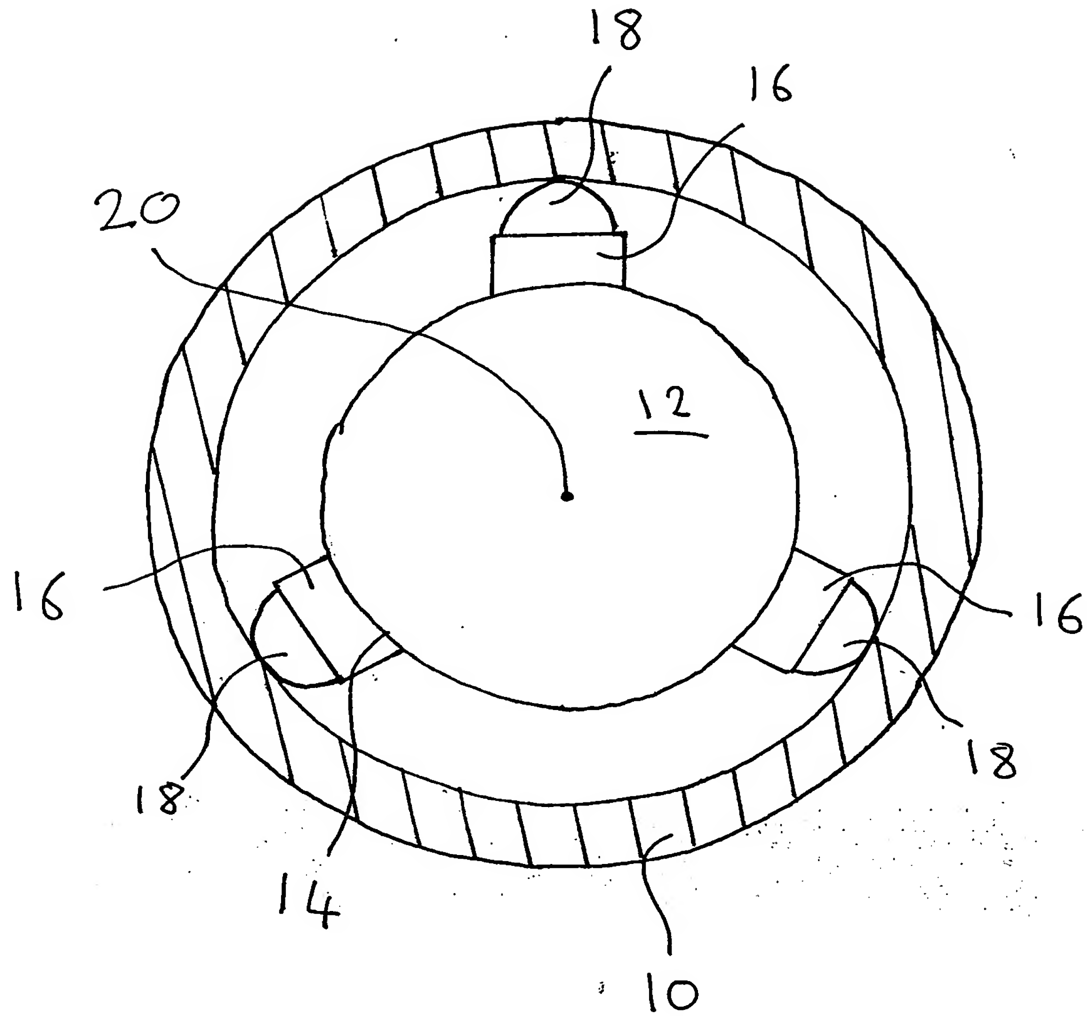
34. The method of claim 33, comprising increasing at least one of the strength and hardness of at least the inner bore wall by strain hardening.

35. The method of claim 33, comprising increasing at least one of the strength and hardness of at least the inner bore wall by cold work.

36. The method of claim 33, comprising increasing at least one of the strength and hardness of at least the inner bore wall by metallurgical transformation.

37. The method of claim 33, comprising increasing at least one of the strength and hardness of at least the inner bore wall by diffusion of elements, which elements promote increased hardness.

38. A metallic tubular having an inner bore wall of relatively high strength and hardness.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